

Doc 9837
AN/454



Manual on Automatic Meteorological Observing Systems at Aerodromes

Approved by the Secretary General
and published under his authority

Second Edition — 2011

International Civil Aviation Organization

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Published in separate English, Arabic, Chinese, French, Russian and Spanish editions
by the
INTERNATIONAL CIVIL AVIATION ORGANIZATION
999 University Street, Montréal, Quebec, Canada H3C 5H7

For ordering information and for a complete listing of sales agents
and booksellers, please go to the ICAO website at www.icao.int

First edition 2006
Second edition 2011

Doc 9837, *Manual on Automatic Meteorological Observing Systems at Aerodromes*
Order Number: 9837
ISBN 978-92-9231-799-7

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AMENDMENTS

Amendments are announced in the supplements to the *Catalogue of ICAO Publications*; the Catalogue and its supplements are available on the ICAO website at www.icao.int. The space below is provided to keep a record of such amendments.

RECORD OF AMENDMENTS AND CORRIGENDA

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Chapter 1

INTRODUCTION

1.1 The purpose of this manual is to help design or update automatic measurement systems for airports and understand the characteristics and limitations of such systems. The manual also deals with performance control and maintenance, as well as with maintaining the optimum operating conditions.

1.2 The chapters in this manual are organized according to parameter type and are presented in the same order as Annex 3 — *Meteorological Service for International Air Navigation*, Chapter 4 and Appendix 3.

1.3 The objective of this manual is not to describe all possible measurement methods; WMO's *Guide to Meteorological Instruments and Methods of Observation* (WMO—No. 8), which is regularly reviewed and revised by WMO as necessary, describes these methods in detail. This manual takes this Guide into account but describes only those aspects which are useful or specific to the field of aeronautical meteorology.

1.4 The *Manual of Runway Visual Range Observing and Reporting Practices* (Doc 9328) describes all aspects related to runway visual range (RVR) and, to a large extent, visibility. This manual therefore does not go into detail about those elements.

1.5 The automatic observation of clouds and present weather is, in particular, an area subject to evolving technological advances. The algorithms used are constantly evolving, making it difficult to standardize them to any great extent. As a result, this manual indicates the basic principles only.

Chapter 2

EXPLANATION OF TERMS

Note.— These explanations are generally based on established scientific definitions, some of which have been simplified to assist non-specialist readers. Approved ICAO definitions are marked with an asterisk () and published WMO definitions¹ with a double asterisk (**). The units, where appropriate, are indicated in brackets.*

Air temperature. The temperature indicated by a thermometer exposed to the air in a place sheltered from direct solar radiation (degree Celsius, °C).

Allard's law. An equation relating illuminance (E) produced by a point source of light of intensity (I) on a plane normal to the line of sight, at distance (x) from the source, in an atmosphere having a transmissivity (T).

Note.— Applicable to the visual range of lights.

Atmospheric pressure. Pressure (force per unit area) exerted by the atmosphere on any surface by virtue of its weight; it is equivalent to the weight of a vertical column of air extending above a surface of unit area to the outer limit of the atmosphere (hectopascal, hPa).

Ceilometer. Instrument for measuring the height of the base of a cloud layer, with or without a recording device. Measurement done by calculating the return time of laser light pulses reflected by the cloud base.

Cloud amount. The fraction of the sky covered by the clouds of a certain genus, species, variety, layer, or combination of clouds.

Cloud base. The lowest level of a cloud or cloud layer (metre, m, or foot, ft).

Convective cloud. Cumuliform clouds which form in an atmospheric layer made unstable by heating at the base or cooling at the top.

Dedicated display. A display connected to a sensor, designed to provide a direct visualization of the operational variables.

Dew-point temperature. Temperature to which a volume of air must be cooled at constant pressure and constant moisture in order to reach saturation; any further cooling causes condensation (degree Celsius, °C).

Disdrometer. A device used for catching the drops of liquid hydrometeors and for measuring the distribution of their diameters.

1. *Guide to Meteorological Instruments and Methods of Observation* (WMO – No. 8).

Extinction coefficient (σ).** The proportion of luminous flux lost by a collimated beam, emitted by an incandescent source at a colour temperature of 2 700 K, while travelling the length of a unit distance in the atmosphere (per metre, m^{-1}).

Note.— The coefficient is a measure of the attenuation due to both absorption and scattering.

Illuminance (E).** The luminous flux per unit area (lux, lx).

Koschmieder's law. A relationship between the apparent luminance contrast (C_x) of an object, seen against the horizon sky by a distant observer, and its inherent luminance contrast (C_0), i.e. the luminance contrast that the object would have against the horizon when seen from very short range.

Note. — Applicable to the visual range of objects by day.

Lightning detection network. Network of lightning detectors transmitting in real time to a central computer, locating lightning flashes by combining information received from each detector.

Luminance (photometric brightness) (L). The luminous intensity of any surface in a given direction per unit of projected area (candela per square metre, cd/m^2).

Luminance contrast (C). The ratio of the difference between the luminance of an object and its background to the luminance of the background (dimensionless).

Luminous intensity (I).** The luminous flux per unit solid angle (candela, cd).

Magnetic wind direction. The direction, with respect to magnetic north, from which the wind is blowing. The magnetic wind directions are used in aircraft operations, necessitated by the magnetic frame of reference applied to air navigation facilities (degree).

Meteorological optical range (MOR).** The length of the path in the atmosphere required to reduce the luminous flux in a collimated beam from an incandescent lamp, at a colour temperature of 2 700 K, to 0.05 of its original value, the luminous flux being evaluated by means of the photometric luminosity function of the International Commission on Illumination (CIE) (metre, m, or kilometre, km).

Note.— The relationship between meteorological optical range and extinction coefficient (at the contrast threshold of $\varepsilon = 0.05$) using Koschmieder's law is: $\text{MOR} = -\ln(0.05)/\sigma \approx 3/\sigma$. MOR = visibility under certain conditions (see Visibility).

Precipitation intensity. An indication of the amount of precipitation collected per unit time interval. It is expressed as light, moderate or heavy. Each intensity is defined with respect to the type of precipitation occurring, based on rate of fall.

Present weather. Weather existing at a station at the time of observation.

Present weather sensor. Sensor measuring physical parameters of the atmosphere and calculating a limited set of present weather, always including present weather related to precipitation.

Prevailing visibility.* The greatest visibility value, observed in accordance with the definition of “visibility”, which is reached within at least half the horizon circle or within at least half of the surface of the aerodrome. These areas could comprise contiguous or non-contiguous sectors (metre, m, or kilometre, km).

Note.— This value may be assessed by human observation and/or instrumented systems. When instruments are installed, they are used to obtain the best estimate of the prevailing visibility.

QFE. Atmospheric pressure at aerodrome elevation (or at runway threshold) (hectopascal, hPa).

QNH. Altimeter sub-scale setting to obtain elevation when on the ground (hectopascal, hPa).

Runway visual range (RVR).* The range over which the pilot of an aircraft on the centre line of a runway can see the runway surface markings or the lights delineating the runway or identifying its centre line (metre, m).

Scatter meter. An instrument for estimating extinction coefficient by measuring the flux scattered from a light beam by particles present in the atmosphere.

Transmissivity (or transmission coefficient) (T). The fraction of luminous flux which remains in a beam after traversing an optical path of a unit distance in the atmosphere (dimensionless).

Transmissometer. An instrument that takes a direct measurement of the transmittance between two points in space, i.e. over a specified path length or baseline.

Transmittance (t_b). Transmissivity within an optical path of a given length b in the atmosphere (dimensionless).

True wind direction. Direction from which the wind blows, measured clockwise from true north.

Visibility.* Visibility for aeronautical purposes is the greater of:

- a) the greatest distance at which a black object of suitable dimensions, situated near the ground, can be seen and recognized when observed against a bright background;
- b) the greatest distance at which lights in the vicinity of 1 000 candelas can be seen and identified against an unlit background.

Note.—The two distances have different values in air of a given extinction coefficient, and the latter b) varies with the background illumination. The former a) is represented by the meteorological optical range (MOR).

Visual threshold of illumination (E_7). The smallest illuminance required by the eye to make a small light source visible (lux, lx).

Weather radar. An adaptation of radar for meteorological purposes. The scattering of electromagnetic waves, at wavelengths of a few millimetres to several centimetres, by raindrops and cloud drops is used to determine the distance, size, shape, location, motion, and phase (liquid and solid), as well as the intensity of the precipitation. Another application is in the detection of clear-air phenomena through scattering by insects, birds, etc., and fluctuation of the refractive index.

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Chapter 3

WIND

3.1 INTRODUCTION

3.1.1 Wind has a direct impact on aircraft. The direction of the prevailing wind is taken into account when planning a new runway. Headwind components determine the direction of take-off and landing and crosswinds force the pilot to compensate for the drift.

3.1.2 An important characteristic of wind is its temporal and spatial variability. Pilots need to be aware of local wind conditions at the airport, especially during approach and departure. Temporal variability makes it necessary to define multiple parameters related to wind: mean, minimum and maximum values. Spatial variability is mostly related to temporal variability and can, for example, lead to a relative movement of gusts (like ripples on a body of water). It can also be related to terrain effects of the aerodrome or its surroundings, or to the presence of obstacles. For these reasons, Annex 3 — *Meteorological Service for International Air Navigation* recommends that wind observations for local reports be representative of the touchdown zone (for arriving aircraft) and of conditions along the runway (for departing aircraft), which sometimes leads to the installation of multiple sensors.

3.2 MEASUREMENT METHODS

3.2.1 Wind measurements in support of aerodrome operations are carried out using anemometers. The most common of the rotating anemometers are cup or propeller anemometers, whose rotating speed is synchronous with wind speed; they are associated with wind vanes. The characteristics of such instruments are well defined in the *Guide to Meteorological Instruments and Methods of Observation* (WMO–No. 8). For these instruments, the time constant is equal to the distance constant, a characteristic of the anemometer, divided by the wind speed. For a classic distance constant of 5 m, the time constant for a speed of 10 m/s (20 kt) is 0.25 seconds. Extreme wind speed values calculated over 3 seconds, as recommended by Annex 3 and the WMO–No. 8, can therefore be easily measured with a cup or propeller anemometer.

3.2.2 There are also static hot-film sensors and ultrasonic sensors. The availability of ultrasonic anemometers on the market is, however, increasing because they do not have moving mechanical parts but are more technically complex and they can de-ice themselves better than most rotating sensors. Ultrasonic sensors also have a short time constant and are able to provide many measurement samples per second. It is, however, important to integrate these measurements over a 3-second period for speed and direction extremes to keep these extreme values from depending on the sampling rate of measurements.

3.3 ALGORITHMS AND REPORTING

Note.— Whilst acknowledging that all specified elements of local routine and special reports and METAR and SPECI are required to be reported, in the event of a temporary failure of a fully automated observing system/sensor which renders the reporting of the surface wind impossible, the group in which the surface wind would have been encoded in the report is to be replaced by an appropriate number of solidi. This practice is in keeping with the Manual on Codes — International Codes, Volume I.1: Part A — Alphanumeric Codes (WMO–No. 306).

3.3.1 Mean speed values

3.3.1.1 There are several methods of calculating mean wind speed. At each instant, a wind vector is available and characterized by its speed and direction.

3.3.1.2 It is possible to calculate the mean wind vector over a given period by calculating the mean of the north/south and east/west components of each instantaneous wind vector, and by extracting the speed and direction of this mean wind vector. This type of calculation might seem logical given the nature of the information (a vector), but it does have some disadvantages:

- a) It depends on the actual availability of direction. If a wind vane breaks down when using an anemometer, the “wind speed” parameter is no longer available;
- b) Mathematically, it can lead to a zero mean wind vector, although there are non-zero instantaneous wind vectors, as a result of a wind change. This case is however theoretical, especially since such a change in wind can result in a marked discontinuity if the wind speed is high enough. Nevertheless, a reduction in the mean wind vector is possible if there is a change in direction with light winds; and
- c) This is not the same method of calculation used in the past when electronic equipment for calculating vectors did not exist. A temporal integration was done on the modulus of instantaneous wind with recorders.

3.3.1.3 It is also possible to calculate separately the mean wind speed using only the instantaneous speed by calculating the mean modulus of instantaneous wind vectors. This method has several advantages:

- a) It does not require the direction, and a breakdown of the wind vane does not result in the absence of calculated speed parameters if there is a requirement to report wind speed without a direction and vice versa;
- b) It is easier to implement; and
- c) It is closer to calculation techniques used in the past.

Its disadvantage is that it gives a mean wind vector that is different from the vector mean of instantaneous winds.

3.3.1.4 ICAO and WMO have not yet provided recommendations on the calculation method, probably since both practices are used throughout the world and a vector calculation would cause problems in several areas. With modern systems, vector calculations are not a problem, especially since they are required for the mean direction. Differences in results between both calculations are minimal when there are few changes in wind direction but are greater when the wind direction shows great variability. If the speed is over 5 m/s (10 kt), there is marked discontinuity. If the speed is less than 5 m/s (10 kt), the differences (in absolute values) between both methods remain minimal.

3.3.2 Mean direction values

3.3.2.1 Similarly, the calculation can be vector or scalar (direct mean of directions), but the scalar mean of directions poses a major disadvantage in relation to the discontinuity of directions between 350° and 10°. The mean of directions varying between 350° and 10°, however, must not be 180°. It is possible to avoid this problem by introducing a drift in the directions, for example by considering a direction of 370° rather than 10°, but applying such a drift that depends on effectively measured directions can be difficult and can cause errors under certain conditions.

3.3.2.2 An example of an algorithm regarding wind direction (1) is given in Appendix A.

3.3.2.3 As a general rule, it is recommended that a vector calculation be performed, using either of these two methods:

- a) by calculating the mean wind vector and its direction; or

- b) by calculating the mean wind vector using the instantaneous vectors of a unit modulus and the direction equal to the measured direction. This method of calculation is somewhat simpler than calculating the actual mean wind vector. Unless there are significant variations in wind speed, it gives equivalent results, while significant variations in wind speed produce marked discontinuity.

3.3.3 Calculating a mean value

Whether the calculation is vector or scalar, the term “mean” should be understood as an arithmetic mean over the given time period.

3.3.4 Calculating extreme values

3.3.4.1 Annex 3 requires that extreme speed and direction values be calculated over a 3-second period. These values should be calculated using measurement samples available every 250 ms (millisecond); however, it is recommended that these values be calculated using measurement samples available at least every second. The calculation should be made as the primary samples become available (e.g. every 250 ms, or at least every second); it should not be made every 3 seconds over a 3-second period, since the calculation would then depend on the calculation time window for wind speed fluctuations, which can be faster than this 3-second period.

3.3.4.2 It is also important for the instantaneous measurement used to be representative of the entire period separating two measurements. If this period is 500 ms, the measurement should be representative of the wind during these 500 ms. This is usually the case with rotating anemometers, whose measurement system counts the number of turns in a given period, which may not be the case for sensors with a faster pace of measurement.

3.3.5 Calculating mean values over 2 and 10 minutes

For local reports, the calculation period is 2 minutes. For METAR/SPECI, the calculation period is usually 10 minutes, but it can be less in cases of marked discontinuity.

3.3.6 Marked discontinuity algorithm

3.3.6.1 Annex 3 defines a marked discontinuity as follows: “A marked discontinuity occurs when there is an abrupt and sustained change in wind direction of 30° or more, with a wind speed of 5 m/s (10 kt) before or after the change, or a change in wind speed of 5 m/s (10 kt) or more, lasting at least 2 minutes.”

3.3.6.2 Examples of algorithms on marked wind discontinuity (2 and 3) are given in Appendix A.

3.3.6.3 When a marked discontinuity is detected, the representative mean wind period (first 2 minutes, increased progressively to 10 minutes) must also be used to find the extreme speed and direction values.

3.3.7 Minimum and maximum speeds

3.3.7.1 Extreme wind speed values must be calculated using values that represent a 3-second period, over an adapted period (usually 10 minutes, but also between 2 and 10 minutes after a marked discontinuity). Extreme values can be calculated over successive 1-minute periods, then combined over the appropriate time period.

3.3.7.2 Maximum speed is included in both local reports and METAR/SPECI if the difference between the maximum and mean speed over 10 minutes (or a lesser time period after a marked discontinuity) is above or equal to 5 m/s (10 kt), in

which case the minimum speed is then also included in local reports. It should be noted that a difference of 2.5 m/s (5 kt) between the maximum speed and the mean speed should be used when noise abatement procedures are applied in accordance with the *Procedures for Air Navigation Services — Air Traffic Management* (PANS-ATM, Doc 4444), 7.2.3.

3.3.7.3 Artificial gusts caused by jet efflux or wake vortices from aircraft may on occasion affect wind measurements. Measuring these artificial gusts should be avoided to the extent possible by appropriately siting the sensors (see discussion on the siting of sensors in 3.4.2). However, perfect siting of sensors may not be possible at many aerodromes. In the event that such artificial gusts cannot be avoided, they may be detected and, if necessary, removed in real time by an automated algorithm as a last resort. An example of such an algorithm on the detection and removal of artificial gusts (4) is given in Appendix A.

3.3.8 Extreme wind directions

3.3.8.1 The sector of variability in 3-second mean directions is limited by the two extreme direction values calculated in the preceding 10 minutes (time increment) and can be defined every minute using 3-second mean directions calculated as the data are received. These directions are placed in a direction histogram with a resolution of 10°.

3.3.8.2 The sector can be found in two steps using the direction of the mean wind in the given 10 minutes. Step one looks for the first limit by scanning the histogram directions counter-clockwise. Step two looks for the second limit by scanning the histogram directions clockwise. In both steps, the desired limit is the direction of the histogram adjacent to a sector with two consecutive directions of zero value. If the occurrence of the condition that determines one or more limits is not met (sector of 360°), the sector is declared undetermined.

3.3.8.3 This search is usually performed over a 10-minute period. After a marked discontinuity, however, the search period is lowered to 2 minutes and then increased progressively to 10 minutes. The wind direction is to be reported as variable if the wind direction varies in accordance with the criteria established in Annex 3.

3.3.9 Reporting wind direction in local reports and METAR/SPECI

Wind directions coded in METAR/SPECI and in local reports are given as the true wind direction, i.e. in relation to True North. However, wind direction provided to pilots, such as via automatic terminal information service (ATIS), is reported as the magnetic wind direction. The difference between reporting true and magnetic wind direction depends upon the aerodrome location in relation to the magnetic North Pole. The difference is sometimes small compared to the 10° coding resolution, but it can reach up to 20° or 30° in higher latitude regions of the world, rising to as much as 180° at the magnetic poles. Any ambiguity about the significance of directions must therefore be avoided between the service providing the observations and the aeronautical user. It is especially important for the controller to avoid performing a mental conversion using a value displayed in relation to True North. Controllers, in providing wind direction to the pilot, are required to report the magnetic wind direction; therefore, the wind displays at the air traffic services (ATS) units should automatically make the conversion from true to magnetic wind directions.

3.3.10 Changes in parameters

3.3.10.1 Wind is a parameter that is very variable in time (gusts) and space. As a result, there are different exposure requirements for sensors used in METAR/SPECI and those used in local reports. Sensors for surface wind observations for METAR/SPECI should be sited to give representative indications of conditions along the whole runway (at aerodromes with one runway) or the runway complex (where there is more than one runway). However, sensors for local reports (provided to aircraft taking-off and landing) are to be sited to give the best practicable indication of conditions along the

runway (e.g. lift-off and touchdown zones). At aerodromes where topography or prevalent weather conditions cause significant differences in the surface wind at various sections of the runway, additional sensors should be installed. Sensors should not be sited close to obstacles that can affect measurements. Obstacles increase turbulence and can make wind direction more variable, leading to unnecessary reporting of wind variations, due to the change criterion of 60° in direction being exceeded artificially as a result of sensors being located close to obstacles.

3.3.10.2 When there are gusts, wind speed can suddenly increase or decrease, which explains the importance of observing both the maximum and minimum speed values. How much the speed changes depends on weather conditions and on the roughness of the surrounding land; rough land produces greater changes. On average, the ratio of maximum wind to mean wind over 10 minutes is close to 1.5, and the ratio of minimum wind to mean wind is close to 0.7.

3.3.10.3 High wind speed variability could make it tempting to use instantaneous wind, giving the impression that reality is being represented more accurately; this is a false impression and instantaneous wind should not be used (Annex 11, 4.3.6.1).

3.3.11 Wind reporting at the touchdown zone (TDZ) with multiple anemometers

3.3.11.1 Sensors for surface wind observations for local routine and special reports should be sited to give the best practicable indication of conditions along the runway and TDZ. Additional sensors should be provided at aerodromes where topography or prevalent weather conditions cause significant differences in surface wind at various sections of the runway.

3.3.11.2 With the presence of more than one anemometer within the same TDZ, there arises an issue concerning how to use the data from the various anemometers (based on an averaging period of two minutes) in the reporting of wind for the TDZ when the wind observations from these anemometers are significantly different, varying by, for example, more than ten per cent from each other. Based on discussions with the aviation users concerned, the following example to report the wind for a TDZ based on multiple anemometers was formulated taking into consideration the flight safety and users' perspectives:

“when data from more than one anemometer are available at the same TDZ, only a single set of mean wind speed, mean wind direction and gust is to be reported to the users based on the readings from the multiple anemometers. The single set is taken as the maximum of the mean wind speeds from the anemometers, the corresponding mean wind direction of the anemometer recording the maximum mean wind speed, and the maximum of the gusts from the anemometers.”

3.3.11.3 It is noted that, given the proposed approach above, the anemometer used for reporting the mean wind speed and direction and the one used for reporting the gust for the TDZ concerned could be different. This is because the anemometer further away from buildings may record a higher value of the mean wind speed owing to a reduced shelter, but the anemometer closer to buildings may record a higher gust owing to the proximity to the turbulence flow associated with the buildings.

3.4 SOURCES OF ERROR AND MAINTENANCE

3.4.1 Sensors

3.4.1.1 Bearings on mechanical sensors can wear down, increasing the starting threshold. Such an increase can cause problems during light winds, but light wind speeds do not affect operations. For greater wind speeds, an increase in the starting threshold does not cause problems, since the torque exerted by the wind on cups or a propeller is proportional to the squared speed, so it quickly and greatly exceeds the resistance corresponding to the starting threshold: if the

threshold is 2 m/s (4 kt), for a speed of 10 m/s (20 kt), the torque will be 25 times stronger. Nevertheless, wear can eventually lead to a blocking of the anemometer or wind vane.

3.4.1.2 One way to monitor the condition of bearings is to check the starting threshold. This can be done in a laboratory, making it necessary to change the on-site sensor. A simple technique can be used to monitor bearings: sheltered from the wind (in a vehicle or building), a pulse is given to the anemometer and the amount of time the rotation stops is measured. If the bearings are worn down, they will stop rotating for a shorter time than those of a sensor in good condition. The minimum amount of time required for the bearings to be considered in good condition depends on the type of anemometer. This method is simple and dependable and can also be used for a wind vane, by replacing the flat surface with cups (to limit aerodynamic braking and increase the inertia of the axis of rotation).

3.4.1.3 Another significant source of error with mechanical sensors is the accumulation of freezing or frozen precipitation on the moving parts. If wet snow clings to the surface of the rotating cups, a marked reduction in wind speed will be reported. Such conditions may also induce wind direction errors by greatly increasing the mass of the vane, reducing its sensitivity to changes. Similarly, freezing precipitation may disable both the wind speed and wind direction by immobilizing the moving parts. Some methods that have been employed to offset this include heating of various components of the instrument and the suppression or flagging of data when errors are likely or suspected.

3.4.1.4 Static sensors can be monitored in a zero wind chamber (in which the sensors are sometimes packaged), available through the sensor manufacturers' catalogues.

3.4.2 Siting of sensors

3.4.2.1 Anemometers should be sited to provide representative wind measurements at an aerodrome. Guidance on siting of anemometers can be found in:

- a) *Manual of Aeronautical Meteorological Practice* (Doc 8896), Appendix 2;
- b) *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8), Part I, Chapter 5; and
- c) *Guide on Meteorological Observing and Information Distribution Systems for Aviation Weather Services* (WMO-No. 731), Chapter 2.

3.4.2.2 In siting an anemometer within an aerodrome, consideration of obstacle clearance rules should be taken into account (see 3.6).

3.4.2.3 The ICAO recommendation for the measurement of height (approximately 10 m) is a compromise between being high enough to avoid surface effects (such as friction) and an installation height that is practical and safe in the aerodrome environment. It is very important to install a sensor in the clearest location possible. As a minimum, it is recommended that any wind-measuring instrument be installed at a distance equal to at least 10 times the height of surrounding obstacles.

3.4.2.4 Sensors must never be installed on the roof of a building, such as a control tower, because the building itself affects the wind flow, which is accelerated at roof level or at the top of the building. For a sensor installed 2 or 3 m above a control tower, speed can be overestimated by 30 per cent. The overestimate will depend on the wind direction and the relative position of the sensor in relation to the edge and shape of the roof.

3.4.2.5 Whilst wind sensors should be located close to the runway(s) to achieve representative wind measurement, every effort should be made to site the sensors to minimize the effect from artificial gusts, e.g. due to jet efflux or wake vortices (see 3.3.7.3).

3.4.3 Orientation of the sensor

3.4.3.1 A wind measurement sensor must be oriented to True North to indicate the direction correctly. The sensor's design plays a part in determining how easily it can be oriented north. The stability of the fastener must also be checked to keep the sensor from rotating over time.

3.4.3.2 For the sensors to be accessible, the fastening mast can often be folded. The mast should have a mark, which must be positioned correctly towards the north. This can be checked with a magnetic compass aligned with the marker and installed in the same place as the sensor or wind vane. Without proper precautions, it is quite possible for alignment errors to exceed 10°.

3.5 CALIBRATION AND MAINTENANCE

3.5.1 For rotating anemometers, the response characteristics are essentially related to the characteristics of the cups or the propeller and wind vane flag. The bearings must be monitored regularly and changed, if necessary. With bearings in good condition, visually monitoring the condition of the cups or the propeller can be enough for the anemometer. An inexpensive way of making sure that these cups or propellers are in good condition is to make a preventative replacement of these elements at regular intervals (e.g. every 2 years).

3.5.2 It is also possible to use a motor whose rotation speed is known in order to train the axis of a rotating anemometer, which makes it possible to control the sensor's transducer.

3.5.3 For static anemometers, a checkpoint is the zero wind chamber test. The stability of the characteristics of measurement ranges depends on the sensor's design. Verifying the sensor's response to the measurement ranges requires a wind tunnel test. For sonic anemometers, the standard used is International Organization for Standardization (ISO) standard 16622.

3.5.4 The orientation of the wind vane must be monitored regularly. If the mast bears a mark for orientation and its design makes it possible to guarantee the stability of its orientation, a simple visual check can suffice. This of course requires the sensor to be designed in such a way as to guarantee that the direction indication is aligned with the mark on the sensor: the quality and stability of the orientation depend largely on the sensor's design.

3.6 MEASUREMENT LOCATIONS

3.6.1 Measurements cannot of course be taken on the runway, and it is important to follow the obstacle clearance rules in Annex 14 — *Aerodromes*, Volume I, Chapter 8, and the *Airport Services Manual* (Doc 9137), Part 6. The minimum distance of a 10-m frangible mast in relation to the runway centre line is 90 m. The mast must be placed in this zone only if absolutely necessary; in most circumstances, a 10-m mast should be at least 220 m from the runway centre line. These criteria are shown in more detail in Figure 3-1.

3.6.2 Multiple wind sensors are recommended for aerodromes subject to changing weather conditions as a result of terrain effects, land or sea breezes, widely spaced aerodromes, etc. Wind measurements for each runway also give a more comprehensive picture of runway conditions for take-off and landing and also provide back-up in case of sensor malfunction.

3.6.3 In METAR/SPECI, the wind measurement must be representative of the runway or runway complex. If only one wind measurement is taken at the airport, this measurement is used both for local reports and METAR/SPECI.

3.6.4 With multiple sensors, one particular sensor deemed the most representative of the runway or runway complex is to be used for METAR/SPECI. In practice, such a sensor position is selected when the measurement system is being designed. Measurements that are too specific for a runway threshold and that would therefore be intended especially for this threshold, because of specific local conditions and not representative of the vicinity of the aerodrome, should not be selected.

3.6.5 With multiple sensors, it may be useful for the observation system to be able to accept a measurement from another suitable anemometer in case the sensor used for METAR/SPECI breaks down.

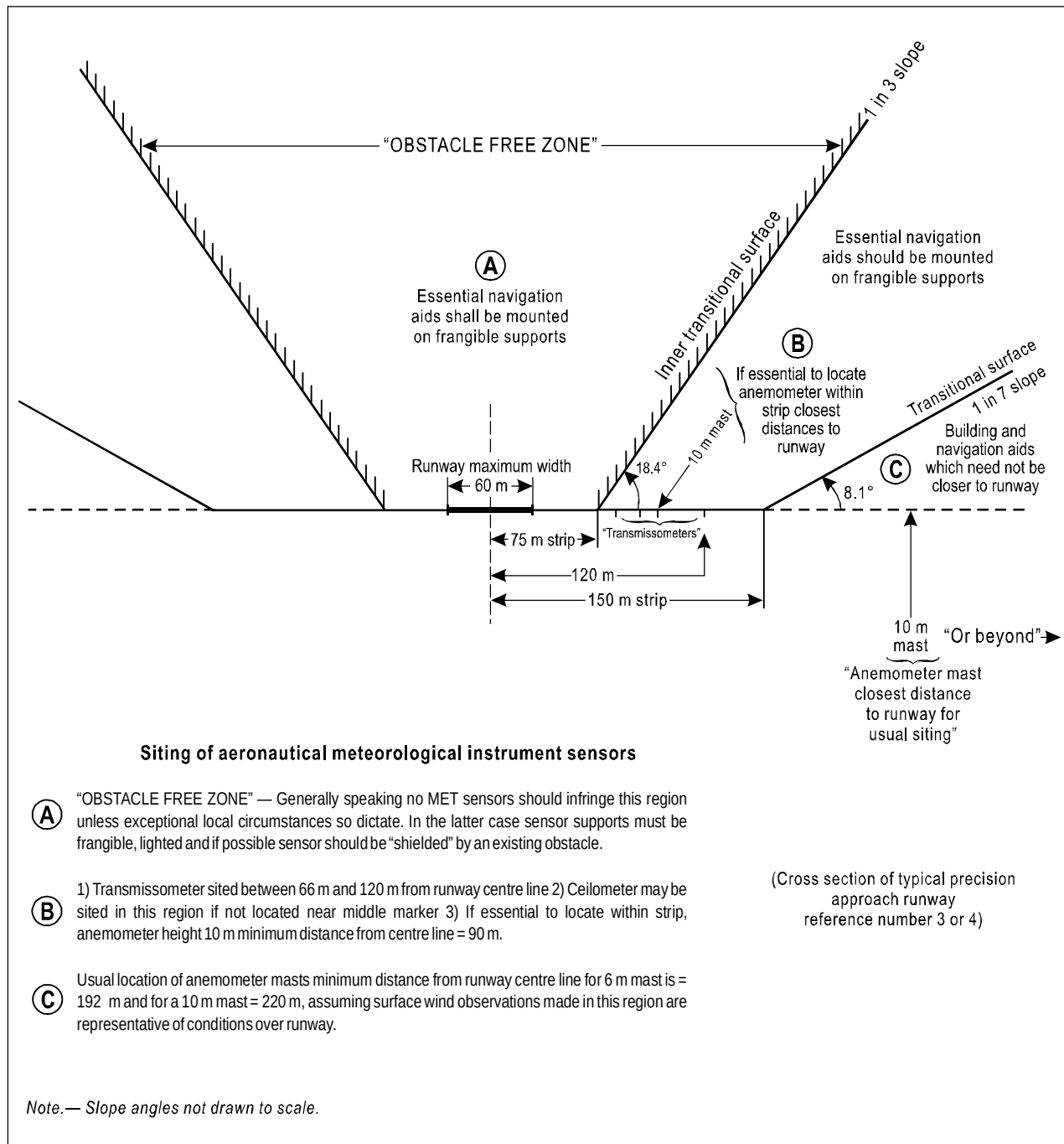


Figure 3-1. Obstacle limitation surfaces

Chapter 4

VISIBILITY

4.1 INTRODUCTION

4.1.1 Visibility is a crucial parameter for aeronautical operations. Low visibility below the approved minimum aircraft and flight crew certification can prevent aircraft from utilizing a runway. Visual aids (markings) and landing and take-off instruments are specifically set up to limit these operational restrictions.

4.1.2 The definition of visibility for aeronautical purposes is:

“Visibility for aeronautical purposes is the greater of:

- a) the greatest distance at which a black object of suitable dimensions, situated near the ground, can be seen and recognized when observed against a bright background;
- b) the greatest distance at which lights in the vicinity of 1 000 candelas can be seen and identified against an unlit background.

Note.—The two distances have different values in air of a given extinction coefficient, and the latter b) varies with the background illumination. The former a) is represented by the meteorological optical range (MOR).”

4.1.3 Visibility in a METAR/SPECI must be representative of the aerodrome, which is a wide area over which significant changes in visibility can take place, so it was necessary to find a synthetic way of describing these changes. Amendment 73 to Annex 3 introduced “prevailing visibility” (Chapter 2 refers).

4.1.4 The *Manual of Runway Visual Range Observing and Reporting Practices* (Doc 9328) describes the atmospheric phenomena that reduce visibility, the different measurement instruments and algorithms; these will not be covered in detail here.

4.1.5 The distinctive characteristics of automatic visibility observations are linked to the possible spatial changes in visibility.

4.1.6 For aeronautical purposes, the measurement range for visibility is from 25 m to 10 km. Values greater than or equal to 10 km are indicated as 10 km. A sensor must therefore be able to measure values above 10 km or indicate if the measurement is greater than or equal to 10 km.

4.1.7 The lower limit is actually linked to the resolution of 50 m required in reports. Measurement instruments often have a resolution smaller than 50 m in low values. Annex 3 specifies that visibility values should be rounded down to the nearest reporting step which means that a visibility value of 45 m will be reported as 0 m. Thus, any measurement of visibility below 50 m should be encoded as 0 m, whilst any visibility measurement between 50 m and 100 m should be encoded as 50 m.

4.2 MEASUREMENT METHODS

4.2.1 Forward-scatter meters are suitable for evaluating the visibility measurement range.

4.2.2 Backward-scatter meters, which are generally more sensitive to the types of scattering particles (fog, dust, sand, rain and snow), should be avoided, except when they are able to identify these particles and take them into account.

4.2.3 A transmissometer has a measurement range linked to its base (distance between the transmitter and receiver). This base is adapted to the RVR range (50 to 1 500 or 2 000 m), which is too short to measure visibilities up to 10 km. However, there are double-base transmissometers that make it possible to cover a greater range of measurement.

4.2.4 There are also prototype systems that use a camera and automatically analyse an image by recognizing (or not recognizing) predefined marks. The advantage of this technique is that it could resemble a human observation and possibly provide an overview, but it would have the disadvantage of referring to a reference point. Continuous functioning in widespread luminance ranges is a difficult matter when trying to avoid sun glare. At night, only the luminous marks can be used, so they must exist. At present, no such validated systems are used.

4.2.5 Not all sensors available on the market perform equally accurately; in fact, there may be significant differences in performance, especially during precipitation. Doc 9328, Chapter 9, describes one method used to test visibility measurement sensors.

4.2.6 Calculating aeronautical visibility also requires the background luminance, measured by a background luminance sensor. Doc 9328, 9.1.5, describes the sensor needed to calculate the RVR. If it exists, it is possible to use the same sensor to calculate visibility. If an RVR system is not installed at the aerodrome, a dedicated background luminance sensor must be installed. It is often associated with a sensor (scatter meter) in order to use its electrical supply, often its support and sometimes its electronic components. Note that sensors now used for automatic visibility observations, as defined in Annex 3, also provide the RVR calculation parameters.

4.2.7 When the background luminance sensor is used to calculate visibility, it must be placed so as to avoid glare from direct light (especially from runway lights) and the sun. Under these circumstances, a single luminance measurement can be used for all visibility points measured by instruments. Nevertheless, in cases of multiple visibility measurements, it is recommended that a second background luminance sensor be installed to replace the first one in case it breaks down.

4.2.8 The number of visibility sensors to be used and their spatial distribution depend on the visibility characteristics of the aerodrome under consideration. This should be subject to research on climatological and local factors. When multiple sensors are used on an aerodrome, in practice, each sensor should be assigned to a sector/area of the aerodrome so that minimum and fluctuating visibility can be reported. The number of sensors to be used and the adequacy of the spatial distribution should be agreed upon by the meteorological authority in consultation with the appropriate ATS authority, operators and others concerned.

4.3 ALGORITHMS AND REPORTING

Note.— Whilst acknowledging that all specified elements of local routine and special reports and METAR and SPECI are required to be reported, in the event of a temporary failure of a fully automated observing system/sensor which renders the reporting of the visibility impossible, the group in which the visibility would have been encoded in the report is to be replaced by an appropriate number of solidi. This practice is in keeping with the Manual on Codes — International Codes, Volume I.1: Part A — Alphanumeric Codes (WMO—No. 306).

4.3.1 General

4.3.1.1 Aeronautical visibility calculations are based on the laws of Koschmieder (contrast visibility) and Allard (visibility from light sources).

4.3.1.2 Calculation methods and formulas are detailed in Doc 9328 and apply to a range of 20 m to 10 km, with an intensity value set at 1 000 candelas. The calculation is more straightforward than the RVR calculation, which must take into account multiple luminous intensities (lights along the edge and on the centre line of the runway) and transition areas related to the directivity of lights and the loss of luminous efficacy outside the optimal axis.

4.3.1.3 An example of an algorithm regarding visibility (5) is given in Appendix A.

4.3.2 Changes in visibility

4.3.2.1 All current visibility sensors directly or indirectly measure the extinction coefficient σ , on a small atmospheric volume. Using a transmissometer, the atmosphere is sampled over a greater distance, the base of the transmissometer, which is a few dozen metres. In both cases, the portion of the atmosphere used for the measurement is local to the sensor. Taking a meteorological optical range (MOR) of several hundred metres or kilometres may seem unreasonable, since the atmosphere analysed is not located kilometres away; the measurement is however representative of large visibility distances only if the visibility is homogeneous, which is usually the case.

4.3.2.2 With a scatter meter, the optical signal during high visibility is very low, but comparing many instruments has proven that certain sensors are capable of measuring high visibility (around 10 km or more) with good comparability and reproducibility.

4.3.2.3 However, for spatial variations in visibility, the indication provided by a sensor only represents where it is installed.

4.3.2.4 For local reports, it is recommended that the visibility be representative of conditions along the runway for departing aircraft and the touchdown zone of the runway for arriving aircraft. Instruments located along the runway and runway thresholds are very well placed to be representative of these zones. Thus, the local representation of instrumented measurements is an asset. A human observer does not have the same advantages during observations, when visibility is low and/or not homogeneous, since the observer is rarely capable of seeing all of the areas concerned.

4.3.3 Visibility in METAR/SPECI

4.3.3.1 In METAR/SPECI, it is recommended that visibility be representative of the aerodrome and, where applicable, provide an indication of changes in direction. The visibility to be reported is the prevailing visibility (Chapter 2 refers). When the visibility is not the same in different directions and when the lowest visibility is different from the prevailing visibility, and less than 1 500 m, or less than 50 per cent of the prevailing visibility and less than 5 000 m, the lowest visibility should also be reported and its general direction in relation to the aerodrome indicated.

4.3.3.2 The advantage of having a human observe visibility using the meteorological station as a reference point is that the observation is based on an overview that covers a large volume of the atmosphere. However, there are limitations related to how effectively objects or lights can be detected by the human eye. For example, as shown in Figure 4-1 a), if the meteorological station and observer are located in a foggy area with a visibility of 300 m, the observer does not see anything beyond those 300 m. Without instruments, the observer therefore cannot be aware of visibility conditions beyond 300 m. The visibility representative of the whole aerodrome is therefore unknown. Conversely, if partial fog is located 2 000 m from the observer as shown in Figure 4-1 b), with a visible mark at 2 000 m, the observer indicates a visibility of 2 000 m, even though visibility in the partial fog is much less (for example, 300 m indicated by a sensor).

4.3.3.3 It is therefore important to understand that instrumented and human visibility observations are comparable only when the atmosphere is homogeneous. When this is not the case, human observation and automatic observation each have their limitations.

4.3.3.4 The concept of prevailing visibility and how it may be established using automatic systems can be explained with the aid of Tables 4-1 and 4-2. In the case of one sensor, only one visibility value can be reported with no directional variations available; therefore, the prevailing visibility only should be reported in this case.

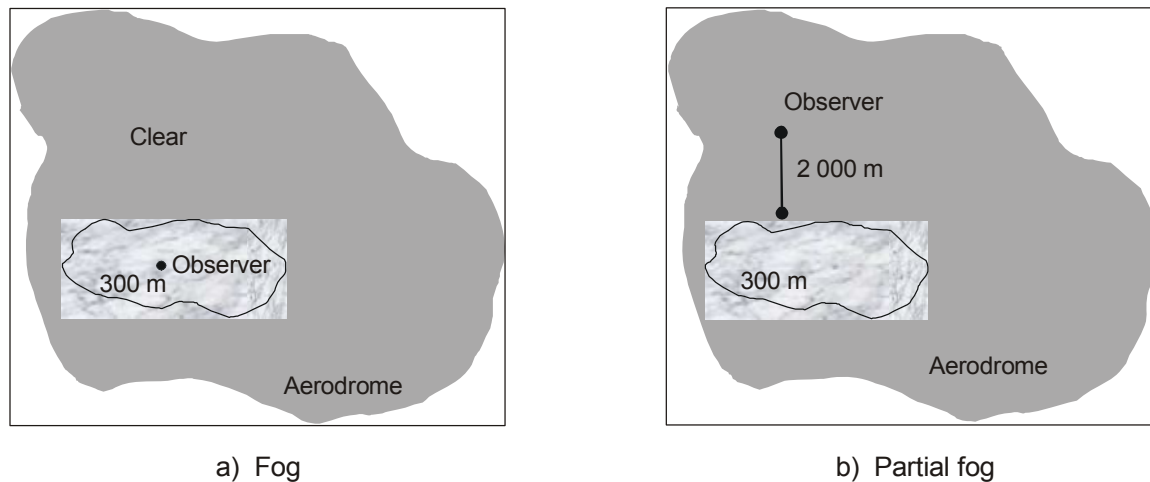


Figure 4-1. Examples of observation errors

Table 4-1. Determining prevailing visibility with one to five sensors

The minimum visibility may also have to be reported, in accordance with criteria in Annex 3, Appendix 3, 4.2.4.4.

Number of sensors	Visibility values observed (Note: $V1 < V2 < V3 < V4 < V5$)	Prevailing visibility to be reported
1	V1	V1
2	V1, V2	V1
3	V1, V2, V3	V2
4	V1, V2, V3, V4	V2
5	V1, V2, V3, V4, V5	V3

Table 4-2. Examples of reporting visibility in METAR and SPECI using five sensors

Sensor (and its location*)	Example 1	Example 2	Example 3	Example 4
Sensor 1 (SE)	3 333	3 333	1 357	3 333
Sensor 2 (NW)	3 455	3 455	1 850	4 455
Sensor 3 (NE)	3 372	3 372	1 900	2 844
Sensor 4 (NE)	3 422	2 400	2 026	1 611
Sensor 5 (SW)	3 520	2 424	1 977	3 520
Values to be reported	3 400	3 300	1 900 1 300SE	3 300 1 600NE
*With reference to the aerodrome reference point.				

4.3.3.5 Table 4-2 provides four examples of how to report visibility with automatic systems using five sensors which are located along the runways and in various sectors in relation to the aerodrome reference point as shown in column one. Example 1 demonstrates a straightforward case whereby measurements from all of the sensors are similar and hence the visibility around such an aerodrome would be homogeneous. In this case, the median value ($V_3 = 3\,422\text{ m}$) should be taken as the prevailing visibility and would be reported as $3\,400\text{ m}$. The median value is taken rather than the mean value to ensure that the prevailing visibility actually represents the true value as observed in part of the aerodrome. Otherwise, it would be possible to have a reported value that was not strictly observed at any part of the aerodrome.

4.3.3.6 Example 2 demonstrates a situation whereby the five sensor readings are split into two groups, i.e. three readings in the range $3\,300\text{ m}$ to $3\,500\text{ m}$ and two readings in the range $2\,400\text{ m}$ to $2\,500\text{ m}$. However, if it is assumed that all the sensors cover an equal area of aerodrome, the definition of prevailing visibility suggests that the visibility would still be reported as the median value ($3\,333\text{ m}$ which would be reported as $3\,300\text{ m}$).

4.3.3.7 Examples 3 and 4 demonstrate situations whereby both the prevailing visibility and the minimum visibility should be reported. Example 3 contains a series of measurements including one measurement below the critical value of $1\,500\text{ m}$. In this case, the prevailing visibility should be reported as $1\,900\text{ m}$ (the median value V_3) with a minimum visibility also reported at $1\,300\text{ m}$. Example 4 shows a similar situation whereby the lowest reading of $1\,611\text{ m}$ is less than 50 per cent of the prevailing visibility value of $3\,333\text{ m}$ (the median value V_3). In this case, both the prevailing visibility and the minimum visibility should be reported as $3\,300\text{ m}$ and $1\,600\text{ m}$, respectively.

4.3.3.8 The examples discussed above make the assumption that each of the sensors used represents an equal part of the aerodrome concerned (e.g. 20 per cent each in Table 4-2) and therefore carries an equal weighting in any calculations made. In some cases, the local climatology of the aerodrome may indicate that sensors may be representative of fog-prone areas or simply may represent more operationally significant parts of the aerodrome. Such considerations should be carried out on an individual basis. In these cases, it would be necessary to establish the percentage of the area of the aerodrome that is nominally to be represented by each sensor. Following this, the prevailing visibility can be derived using its definition which requires that the prevailing visibility is the visibility value reached or exceeded within at least half of the surface of the aerodrome.

4.3.3.9 Annex 3 provisions also state that when the visibility is fluctuating rapidly and prevailing visibility cannot be determined, only the lowest visibility should be reported. This case applies only for visibility assessed by a human observer, because with automatic systems, it is always possible to determine prevailing visibility.

4.4 SOURCES OF ERROR

The spatial variability of visibility is the main source of error when visibility is not homogeneous. In fact, this variability must be considered each time comparisons between instruments or between instruments and human observations are made. Doc 9328, Chapter 9, describes a method of evaluating performances and a method of detecting spatial inhomogeneities by analysing temporal variability.

4.5 CALIBRATION AND MAINTENANCE

4.5.1 Instruments must be calibrated regularly according to the manufacturer's instructions. It is usually recommended that instruments be monitored every six months, and experience shows that settings typically remain stable over such a period. The calibration of a scatter meter is based on the use of a scattering plate (or plates) providing a constant scattering signal. The relation of the signal level to visibility should be defined by measuring the scattering from the plate with sensors compared regularly to reference transmissometers in a variety of weather conditions. This process is described in Doc 9328, Chapter 8.

4.5.2 It is important to avoid any unwanted optical reflection that causes, on a scatter meter, an increase in the signal scattered and therefore an MOR indication that is too low. This can be caused particularly by spider webs. Optical

surfaces must therefore be maintained more often than they are calibrated. Many models monitor the contamination of their optical surfaces and are able to warn the acquisition system when their performance declines or their surface requires cleaning. Scatter meters should be capable of detecting optical path blocking, as lower signal values are interpreted as higher visibility leading to potentially unsafe conditions.

4.5.3 It is also important to avoid unwanted reflections from plant life. Care must be taken to ensure that the surrounding land is clean and that there is no plant life to attract flying insects that could enter into the measurement volume. Another way of avoiding these problems is to set up the measurement volume high above the ground, which is in fact recommended (a measurement height of approximately 2.5 m should be used, which is a height also used for RVR assessment).

4.5.4 The background luminance sensor used for calculating visibility must also be cleaned and calibrated regularly according to the manufacturer's instructions. A measurement uncertainty of 10 per cent is considered acceptable.

4.5.5 Snow on the ground can also affect the measurement of the scattered signal because it increases the continuous signal picked up by a receiver of the scatter meter. In case of heavy accumulations of snow, the surface of the snow must not be too close to the scattering volume. It is important to remove the snow from around the sensor and/or install the sensor high enough to avoid contamination by snow.

4.5.6 If there is snow on the ground, significant errors can take place if snow drifts or blows into the scattering volume. For sites subject to this, the measurement head should be raised.

4.5.7 Drifting and blowing snow can obstruct the optical heads of a scatter meter. Instruments usually have a heating mechanism to avoid such blockage, but it may not provide enough heat in extreme conditions. It is therefore important to clear the optical heads of snow. The danger in such circumstances is that the obstruction of the optical path causes a reduction in the signal scattered and therefore an overestimate of the MOR. Certain sensors are designed to indicate such circumstances.

4.5.8 There have been limited calibration tests performed on forward-scatter systems in conditions of blowing sand or dust. The lack of performance data, combined with the uncertainty of the relationships between the scatter meter and extinction by lithometeors, may introduce errors in such conditions. Typical lithometeors would exhibit a higher degree of absorption than would be expected from hydrometeors.

4.6 MEASUREMENT LOCATIONS

4.6.1 Sensors should be installed in the area that is most representative of the operating area of the aerodrome. It can be done based on climatological (directional visibility information extracted from old reports) and local conditions (e.g. presence of water that may be a source of visibility reduction and buildings that can form the boundary of a sector). Such locations must also respect the manufacturer's clearance rules and, most importantly, must not be too close to buildings. Ease of access for sensor maintenance and connection to the acquisition system will also be factors in the choice of location of the sensors.

4.6.2 When multiple sensors are installed, it is usually better to estimate the visibility conditions in the landing and take-off zones. The locations of the runway thresholds used for RVR measurements are therefore well placed. The location is described in Annex 3 and in Doc 9328, Chapter 5. In fact, the same sensors, especially scatter meters, can be used to determine the RVR and visibility.

4.6.3 If there is an area of the aerodrome that is particularly subject to unfavourable visibility conditions, such as a zone prone to advection fog, it is recommended that a sensor be installed in that area.

Chapter 5

RUNWAY VISUAL RANGE

5.1 INTRODUCTION

5.1.1 Doc 9328 covers all aspects related to RVR. These elements will not be dealt with here.

5.1.2 Annex 3 stipulates that scatter meters can be used to measure the extinction coefficient used to calculate RVR. Contrary to most transmissometers, a scatter meter can also cover the visibility measurement range. It is therefore natural and recommended to use the measurements from a scatter meter to calculate both RVR and visibility. This of course requires that the scatter meter be installed according to the Standards and Recommended Practices of Annex 3.

5.2 REPORTING IN METAR/SPECI

Note.— Whilst acknowledging that all specified elements of local routine and special reports and METAR and SPECI are required to be reported, in the event of a temporary failure of a fully automated observing system/sensor which renders the reporting of the runway visual range impossible, the group in which the runway visual range would have been encoded in the report is to be replaced by an appropriate number of solidi. This practice is in keeping with the Manual on Codes — International Codes, Volume I.1: Part A — Alphanumeric Codes (WMO—No. 306).

When RVR is coded in a METAR/SPECI, Annex 3 recommends including only the value or values representative of the touchdown zone, that is, the landing threshold of the runway in use. Since the airport authority and not the meteorological service determines which runways are in use, the meteorological service must be made aware of which landing thresholds are in use. In a system that is fully automatic (or functioning during a period in fully automatic mode), the system does not know which threshold or thresholds are in use. In such cases, the RVR for up to four instrumented thresholds is reported in METAR/SPECI when conditions requiring RVR data are met (visibility or RVR below 1 500 m).

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